Radar in World War II: The South African contribution

by B. A. Austin

The science and engineering of radar are not much more than fifty years old and recently that brief history has been the subject of much examination. Although the contributions of the major powers towards the development and use of radar are well known, very little has been published about the pioneering work done in other countries, particularly those in the southern hemisphere. This paper describes the development and operational use of a radar system by the South Africans at the outbreak of World War II. The success of that major undertaking was due to the key people involved and their role in this saga is emphasised.

The significant role played by radar in World War II is well known and the technical details have recently been extensively documented[1–3]. What is not generally known though is that radar equipment was designed and developed in great haste and under a shroud of secrecy at the very early stages of the war in countries not usually associated with such activities. The impetus for this work came from an official disclosure which Britain made early in 1939 to countries of her Commonwealth on the existence of a system of radio direction finding, or RDF as it was then known[3,4]. The text of the secret telegram sent on 27th February 1939 from South Africa's High Commissioner in London, announcing this to his Department of Foreign Affairs, read[4]:

> 'Please inform Minister of Defence that Sir Kingsley Wood and Air Marshall Sir Cyril Newall disclosed to High Commissioner under promise of absolute secrecy certain technical developments which are of vital importance against air attack…'

Fig. 1 B. F. J. Schonland, the driving force behind South Africa's radar developments



It went on to request that someone from South Africa, 'possessing the highest possible qualifications in physics', should be sent to London for a period of two to three months to become fully acquainted with these new principles, so that technicians and operators could be trained to use the equipment as and when it became available[4,5].

As it transpired, nobody was sent from South Africa; instead a Major Wilmott, a Union Defence Force (UDF) officer serving in London, was ordered to liaise with the British authorities. Meanwhile Dr. Ernest Marsden, the Secretary of the New Zealand Department of Scientific and Industrial Research, had been briefed on this new technique in England and it was arranged that he should in turn brief the South Africans on his return to New Zealand via Cape Town[4].

The choice of the South African scientist to meet Marsden was an inspired one. Professor B. F. J. Schonland, FRS, (Fig. 1) was Professor of Geophysics at the Bernard Price Institute (BPI) of Geophysical Research at the Univesity of the Witwatersrand in Johannesburg. A brilliant scientist as well as a man of immense drive and personality, Schonland was born in Grahamstown, graduated in physics at Rhodes University College there, and then was a research student at Cambridge under Rutherford. He joined the British Army in 1915 and served with distinction as a signals officer in France. On his return to South Africa he was a pioneer in the study of lightning and it was with this background that he was sent to Cape Town to meet Marsden on 14th September 1939[4]. They travelled together by sea to Durban, a journey of some two to three days at that time, during which they had detailed discussions and Schonland made notes from the 'RDF manual' which Marsden had brought with him from England. In Durban (Fig. 2) Schonland enlisted the assistance of a close colleague, D. B. Hodges, Professor of Physics at the Natal University College, who, with W. E. Phillips, senior lecturer in electrical engineering, made glass photographic slides from Marsden's RDF Manual[4,6].

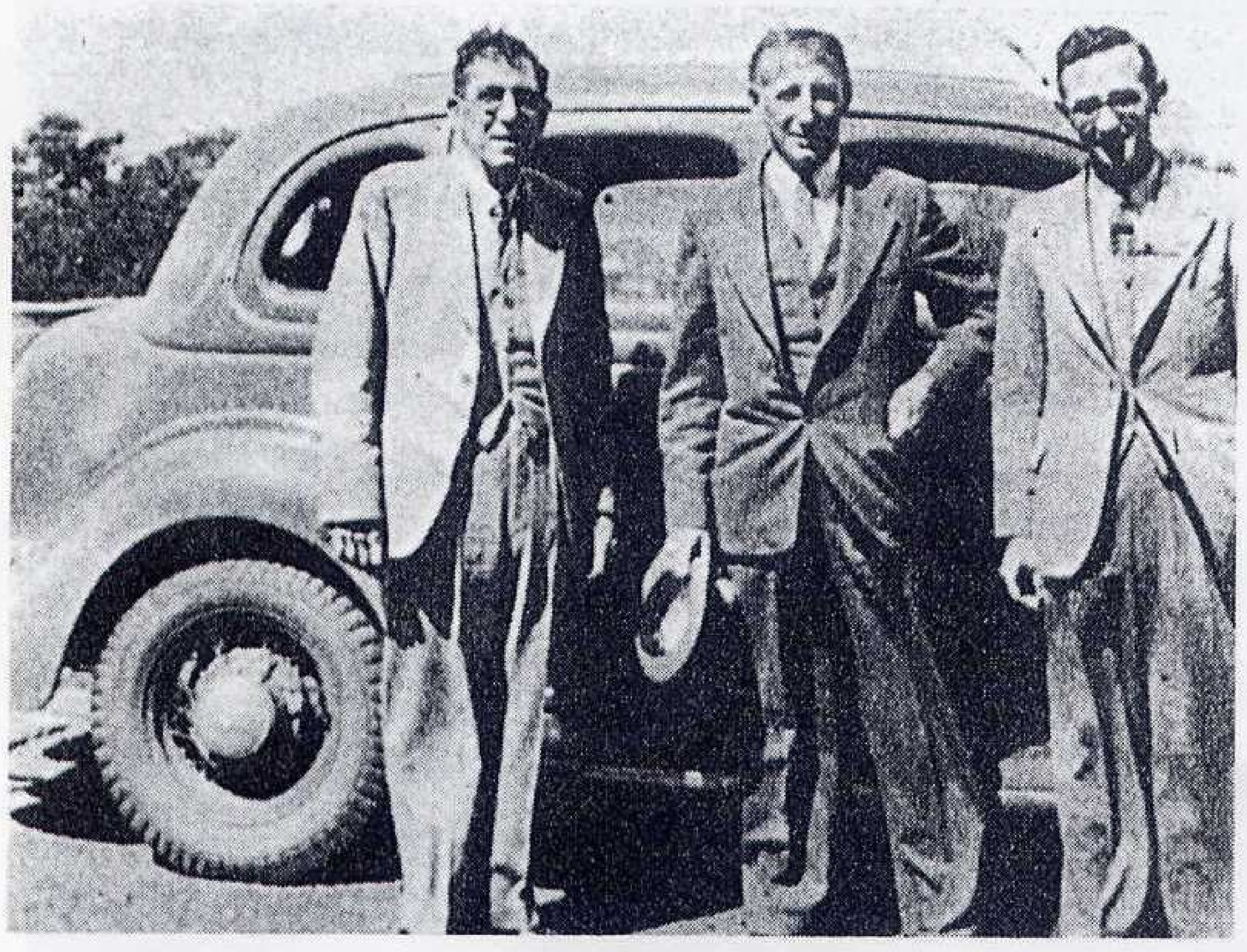


Fig. 2 D. B. Hodges, B. F. J. Schonland and W. E. Phillips in Durban in September 1939

When Schonland returned to Johannesburg, his report caused the South African Prime Minister, General J. C. Smuts, to request that the resources of the BPI be devoted entirely to 'work of a special nature' for the duration of the war[7]. The obvious need for close co-operation with the military authorities meant that the project fell under the jurisdiction of the South African Corps of Signals (SACS) and Schonland was officially authorised to proceed on 18th September 1939[4]. It was envisaged that the first British radars, which were to be used for coastal defence, would only arrive in South Africa early in 1940 and therefore, in order for the scientists to gain some familiarity and experience with the principles involved, a South African radar would be designed and constructed based on Schonland's notes and the precious glass photographic slides.

Background

At this point it is useful to examine the state of radar development as it was at this stage of the war in England[1,3]. This will help to understand the thought processes of Schonland and his team when they commenced their design. It would seem reasonable to assume that those notes and slides from Marsden's RDF manual would have contained the essence of this information. Unfortunately, few of these artefacts have survived the secrecy of the war for this to be confirmed.

The Chain Home (CH) radar in England had been developed as an early warning system, following Watson–Watt's famous Daventry experiment in February 1935, and was operational around the south and east coasts of the country by late 1938. Of particular importance, when the specification of the South African radar is examined, is the fact that all CH radars operated on the so-called flood-lighting principle where a fixed region in front of the stationary transmitting antenna was illuminated by the radar energy. Any target within that area of space would then cause a reflection of energy from which a goniometer system, associated with the separate receiving antenna, could determine the target bearing. Noteworthy too is the frequency range within which the CH radars operated. This was from 22 to 27 MHz[1,3]. The benefits of using both a rotating beam to scan an area as well as a higher frequency for better target resolution with a given antenna size had been considered from the outset in 1935 but the need for a proven and reliable radar in the shortest possible time was the overriding reason for using the low-frequency, fixed-beam approach[3]. It should be noted too that the CH radar was not capable of detecting low-flying aircraft since its antenna system did not produce a beam below about 2° of elevation. Hence it was also ineffective against shipping.

To overcome this problem the development commenced, late in 1938, of a Coast Defence (CD) radar. This system operated at 200 MHz and used a four-tier array of horizontal, full-wave dipoles, with five dipoles per tier spaced a distance of one-eighth of

a wavelength in front of a wire mesh reflector. During development both Yagi and Sterba-type antenna arrays had also been used with this radar. Initially, too, separate antennas were used on the transmitter and the receiver. Subsequently though, a common antenna with transmit–receive (TR) switching was introduced when this equipment went into service as the Chain Home Low or CHL radar[3].

The effects of antenna polarisation had been examined in experiments at Orfordness as early as 1936. The orientation of aircraft suggested that they would behave predominantly as horizontally polarised scatterers of radar energy. The experiments showed though that the radar range obtained was not a function of polarisation and that considerably more ground and sea clutter occurred with vertical polarisation. Thus the horizontal mode was chosen for these early British radars.

Finally the modulation circuits used in the CH radar were designed to produce pulse lengths from 5 to 45 microseconds at pulse repetition frequencies of 50, 25 or 12·5 Hz. The time-base which controlled the horizontal deflection of the display and its range markers, and which also triggered the transmitter, was loosely locked to a preset point on the 50 Hz mains supply waveform by what was known as a 'spongy lock'[3]. This ensured that small frequency and amplitude variations in the supply were absorbed without affecting the lock. Whereas this was vital to the operation of the multistation CH system it was to prove a major problem in the South African radar in the field, as we shall see.

The South African radar

With this as the presumed state of his knowledge of British radar, Schonland assembled his design team to commence work on producing South Africa's own radar (Fig. 3). Its members were W. E. Phillips from the Natal University College, G. R. Bozzoli from the University of the Witwatersrand, N. H. Roberts from the University of Cape Town—all senior lecturers in Electrical Engineering—and P. G. Gane, a geophysicist and senior research officer at the BPI. Clear areas of design responsibility were assigned to each and these were as follows: Schonland, as well as maintaining overall administrative control, designed the antenna system; Bozzoli designed the RF stages and Phillips the IF stages of the receiver; Roberts produced the display unit and the time-base system and Gane designed the transmitter[4].

A frequency of 90 MHz was used. Why this should have been chosen has been a subject of some conjecture. Bearing in mind that the application of

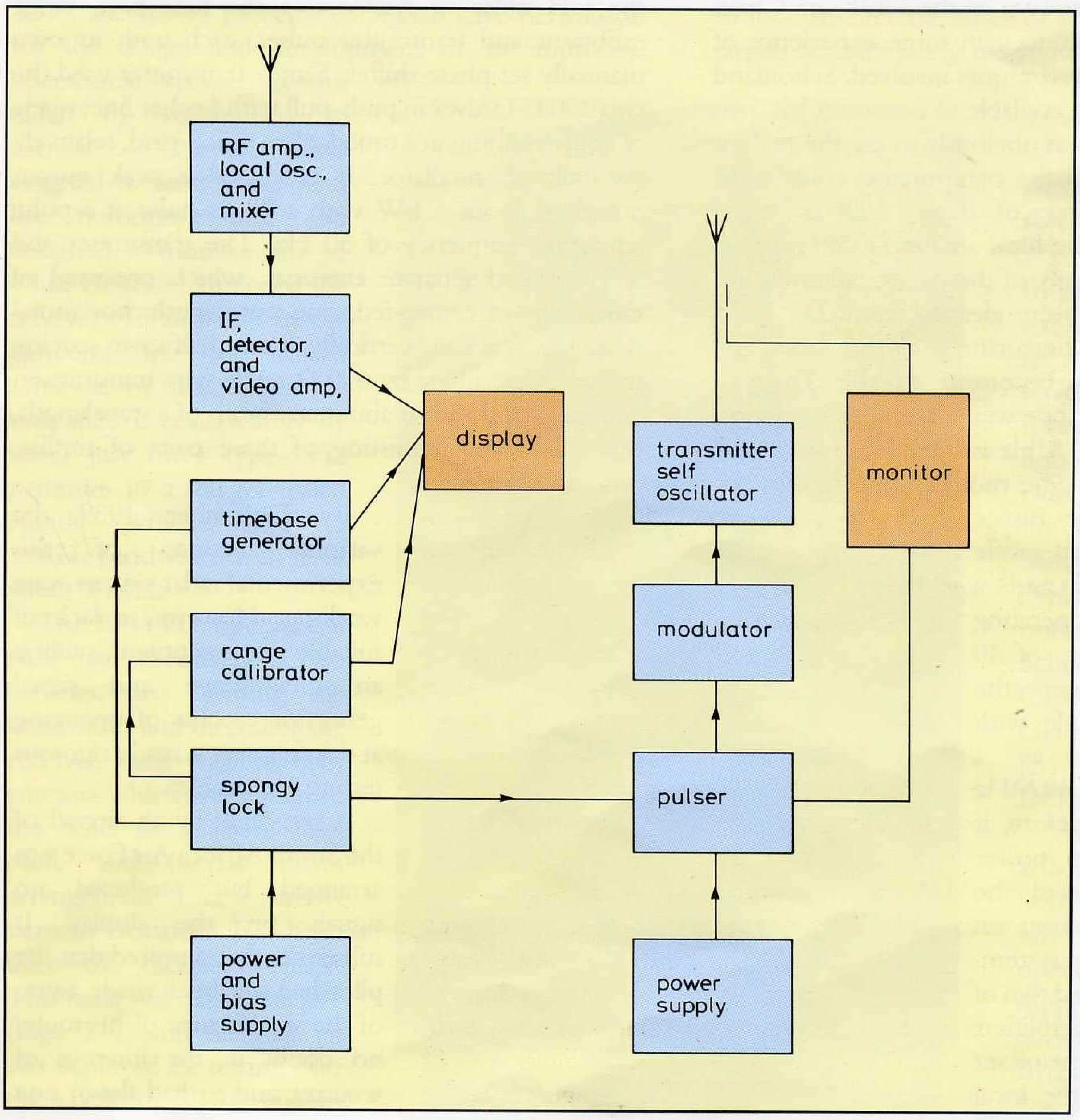


Fig. 3 Block diagram of the JB radar



Fig. 4 Northcliff Hill and water tower: the first radar target in South Africa

radar in South Africa at this stage of the war was for coastal defence against hostile shipping and also possibly against low-flying Japanese aircraft, the need was for a radar of the type expected to arrive in the country from England early in 1940[4,6]. These sets operated at 200 MHz and were semitropicalised versions of the CHL known as the COL, or Chain Overseas Low, radar. So, to gain some experience of the undoubtedly novel techniques involved, Schonland decided to use the time available to construct his own radar and the decision was obviously to use the highest frequency possible with the components available to them. The main source of these, such as high-frequency valves, was the local amateur radio supplier in Johannesburg and many of the circuit, antenna and transmission line ideas were gleaned from *The Radio Amateur's Handbook*[5,8]. Fortunately, at that time, the RCA 'acorn' valves were becoming available. The type 956 pentode and 955 triode were capable of operation at frequencies above 300 MHz as amplifiers, mixers and oscillators in receivers. The most suitable transmitter valve available was the Eimac 250TH, a triode with an anode dissipation of 250 W and a maximum quoted operating frequency, at full rating, of 40 MHz. Somewhat later the Gammatron 354E triode with 150 W dissipation at a maximum frequency of 30 MHz was used[8]. Clearly, therefore, it was the transmitter power amplifier which imposed the upper frequency limitation on this experimental radar system.

Bozzoli's RF stage used two of the 956 pentodes as amplifiers followed by another as the mixer with a 955 triode as the local oscillator. The IF amplifier, which Phillips designed, drew heavily on the techniques used in television receivers of the day. Both circuits were of conventional design. However, the time-base generator designed by Roberts was a complicated system which used a thyratron, with the same 'spongy lock' technique as in the CH radar to synchronise the time-base, range calibrator and transmitter pulser, each with its own manually set phase shifter. Gane's transmitter used the two 250TH valves in push-pull with Lecher lines made of copper tubing in a tuned-plate tuned-grid, relatively low-voltage, oscillator. It produced a peak output power of about 5 kW with a 20 μs pulse at a pulse repetition frequency of 50 Hz. The transmitter and receiver used separate antennas, which consisted of three pairs of centre-fed, one wavelength, horizontal elements, stacked vertically with halfwave spacing and all fed in phase by 600 Ω open-wire transmission line. Behind them, at about an eighth of a wavelength, was a reflector consisting of three pairs of similar, parasitic elements[8].

On 16th December 1939 the first radar echo was received

By December 1939 the various sections of this experimental radar system were working. However, a lack of suitable test equipment, such as an oscilloscope and signal generator capable of operating at this frequency, made rigorous testing impossible[5].

A test flight by an aircraft of the South African Air Force was arranged but produced no signals on the display. It subsequently transpired that the pilot had not been made aware of the significance of his route, no doubt in the interests of security, and so had flown one

of his own choosing rather than that which had been carefully selected for him! Soon after, an attempt to use a target consisting of a mesh of copper wires suspended beneath hydrogen-filled balloons and launched from about 10 km from the BPI was also unsuccessful. Then it happened. On 16th December 1939, after further work on the equipment, the first radar echo was received[4,5]. The 'target', quite by chance, was a well-known Johannesburg landmark known as the Northcliff Water Tower (Fig. 4) at a distance of about 8 km from the BPI. With a target, and a fixed one at that on which to adjust the radar, further tuning was possible and soon strong echoes were received from a range of mountains 100 km away.

This first South African designed radar was called the JB0. It was the product of Schonland's vision and drive and of the design skills and ingenuity of his team of Bozzoli, Gane, Phillips and Roberts. Remarkably, it was operating within three months of his meeting with Marsden.

In January 1940 the team was joined by a young physics graduate, F. J. Hewitt, from Schonland's Alma Mater, originally recruited some time before to work on lightning research. He was destined to become a key member of the team. By this time it had become clear that the arrival of any British equipment in South Africa would be delayed indefinitely and so, in March 1940, the army's Director of Signals gave permission for the design and development of an improved, operational version of this radar to commence in earnest[4,6]. Hewitt was assigned to assist Gane with the transmitter and also designed a monitor for it, while Bozzoli redesigned the receiver's IF amplifier in the light of the test results achieved by that stage. He simplified it considerably by using just three type-1852 pentodes in a stagger-tuned circuit which gave a 1 MHz bandwidth at an IF of about 9 MHz.

The BPI's first operational radar was assembled in two vehicles, one housing the transmitter and the other the receiver, each with its own antenna which was linked to the other by a 16 m steel cable and bicycle chain arrangement for simultaneous rotation by hand from the receiver vehicle. This radar was called the JB1 (Figs. 5–7) and the first set was deployed for testing over the sea from Signal Hill in Cape Town in June and the second, from Avoca near Durban, in July 1940. At this stage it was decided to subsume those members of this special radar development team involved in these field trials into a military unit and so they became members of the South African Corps of Signals (SACS)[4], with Major Schonland as the CO in the rank he had held[9] in 1919.

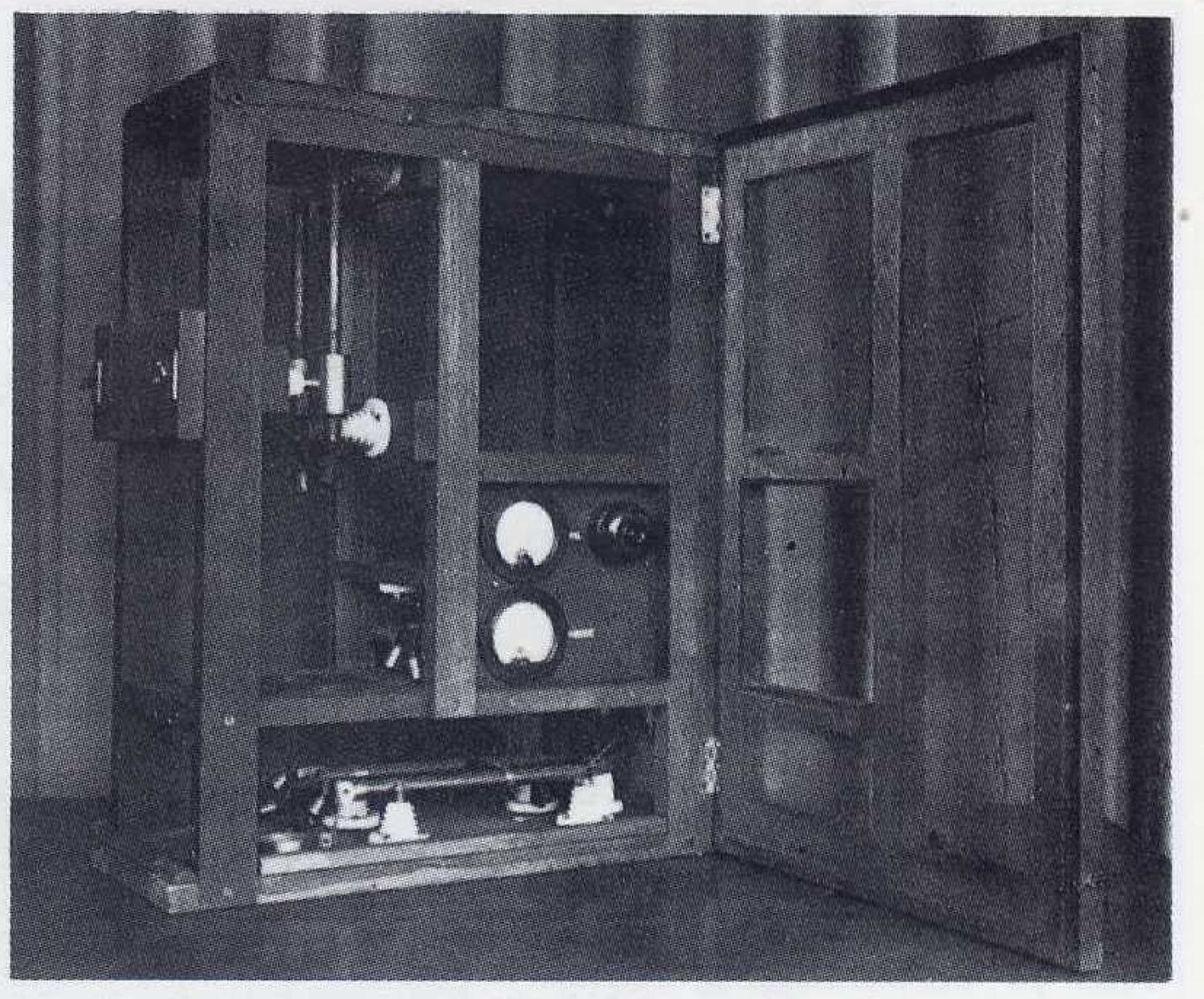


Fig. 5 JB1 radar transmitter without its valves

These first coastal tests with the radar were most successful. Trials aircraft, as well as much shipping, were seen on the cathode ray tube and the radar was found to have an effective range of about 50 km, with some targets actually being beyond the optical horizon due to the phenomenon of superrefraction[5,10].

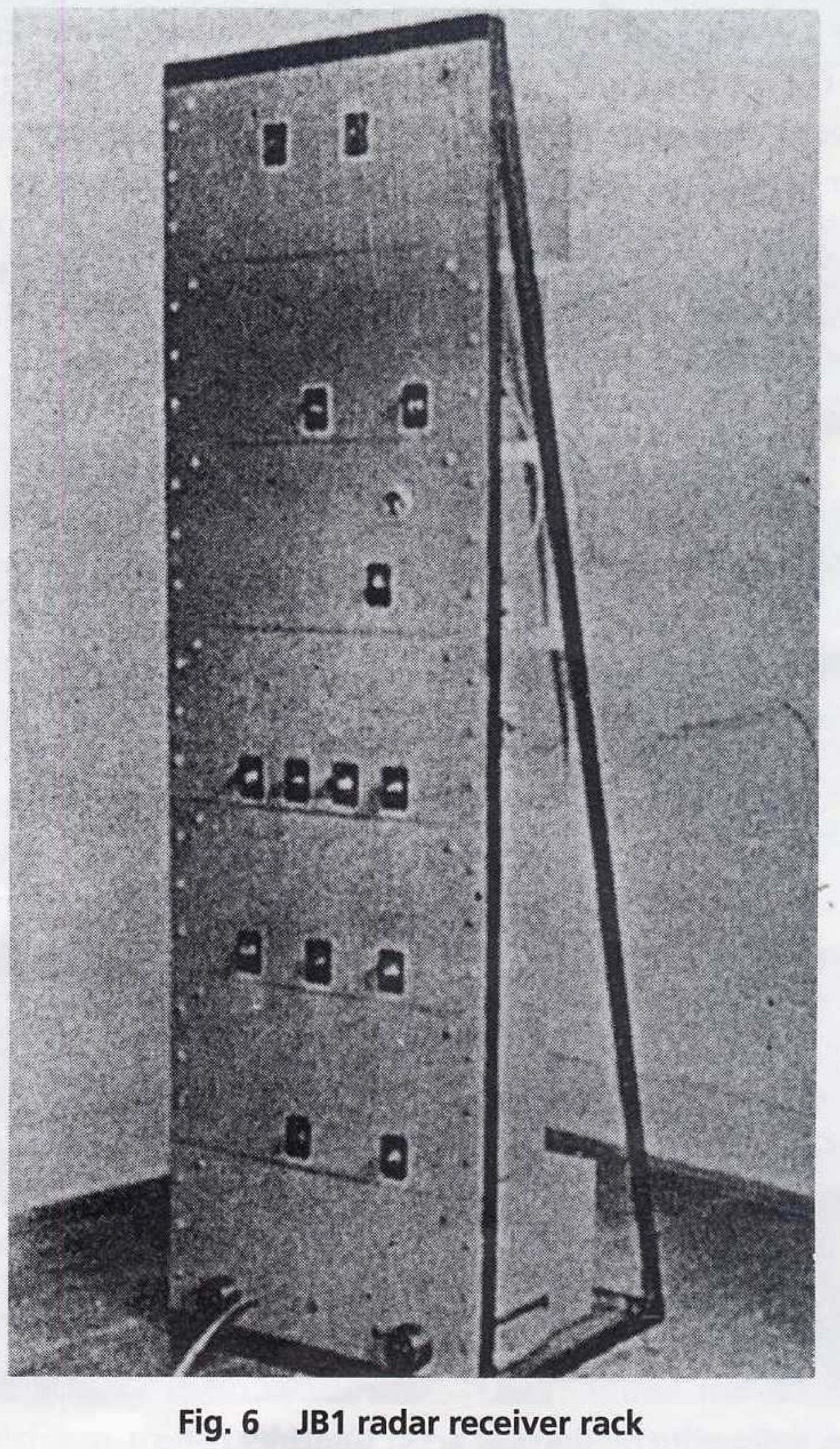


Fig. 6 JB1 radar receiver rack

Active service in East Africa

By mid 1940 operational requirements in the East African campaign, in the form of the threat from Italian air attack and the non-availability of British radar for that theatre, caused the Chief of the General Staff to order the deployment of the radar north of Mombasa. Schonland flew up while Captain Gane and Lieutenant Hewitt moved a JB1 radar by sea from Durban.

The equipment was sited at Mambrui, about 160 km north of Mombasa, on 27th July 1940 and it was operational by 1st August, supporting the anti-aircraft guns manned by the 1st AA Brigade[5]. This installation was followed soon after by

four others in the vicinity of Mombasa with the last being deployed[4] on 16th February 1941. This first use of the JB1 in anger, as it were, was not without its problems. One of the first of these occurred when the radar was powered from a diesel generator with its inherently unstable supply frequency. The spongy lock was quite incapable of operating under such conditions and this caused the range calibrator to vary wildly. This problem forced Hewitt to do some drastic redesign in the field to overcome it[5,10].

The South African radar team became known as the Special Signals Services, or SSS

No high-altitude calibration flights could be arranged and so the performance of the radar could only be assessed by observing a scheduled flight by an aged aircraft which was tracked daily as it flew along the coast at a height of 150 m for about 35 km. However, when two Italian bombers strayed further south than usual after bombing an airstrip near Malindi, the JB1 tracked them going out to sea for some 55 km, not having detected their approach because of the limited coverage of the antenna. The problem was later solved when a fully rotatable, dual, antenna system, developed by Bozzoli in Johannesburg, was installed, but soon breaking feeder cables became the problem! Gane's original low-voltage transmitter performed very well when set up by its designer. However other users reported great difficulty with it and so Bozzoli redesigned it to operate at a higher voltage and it was then much more docile. Much of the original JB0 circuitry had since been redesigned by Bozzoli at the BPI and the success which the radar now achieved was a tribute to his engineering skill[5].

By this time the specific role being played in the war effort by this group of engineers, scientists and their supporting technicians and operators had been recognised with their designation, within the South African Corps of Signals, as the Special Signals Services, or SSS as they were subsequently known. Major D. B. Hodges had by now been appointed as Schonland's second in command and proceeded to recruit young graduates for special training in the new field of radar. Meanwhile a programme of construction of new equipment commenced under Major Bozzoli at the BPI[4].

The Middle East

In December 1940 Schonland flew to Cairo for discussions with the RAF Chief Radio Officer in the Middle East, Wing Commander J. A. Tester[4]. Evidently there was a requirement in Crete, Greece, Aden and elsewhere for 'a more portable type of

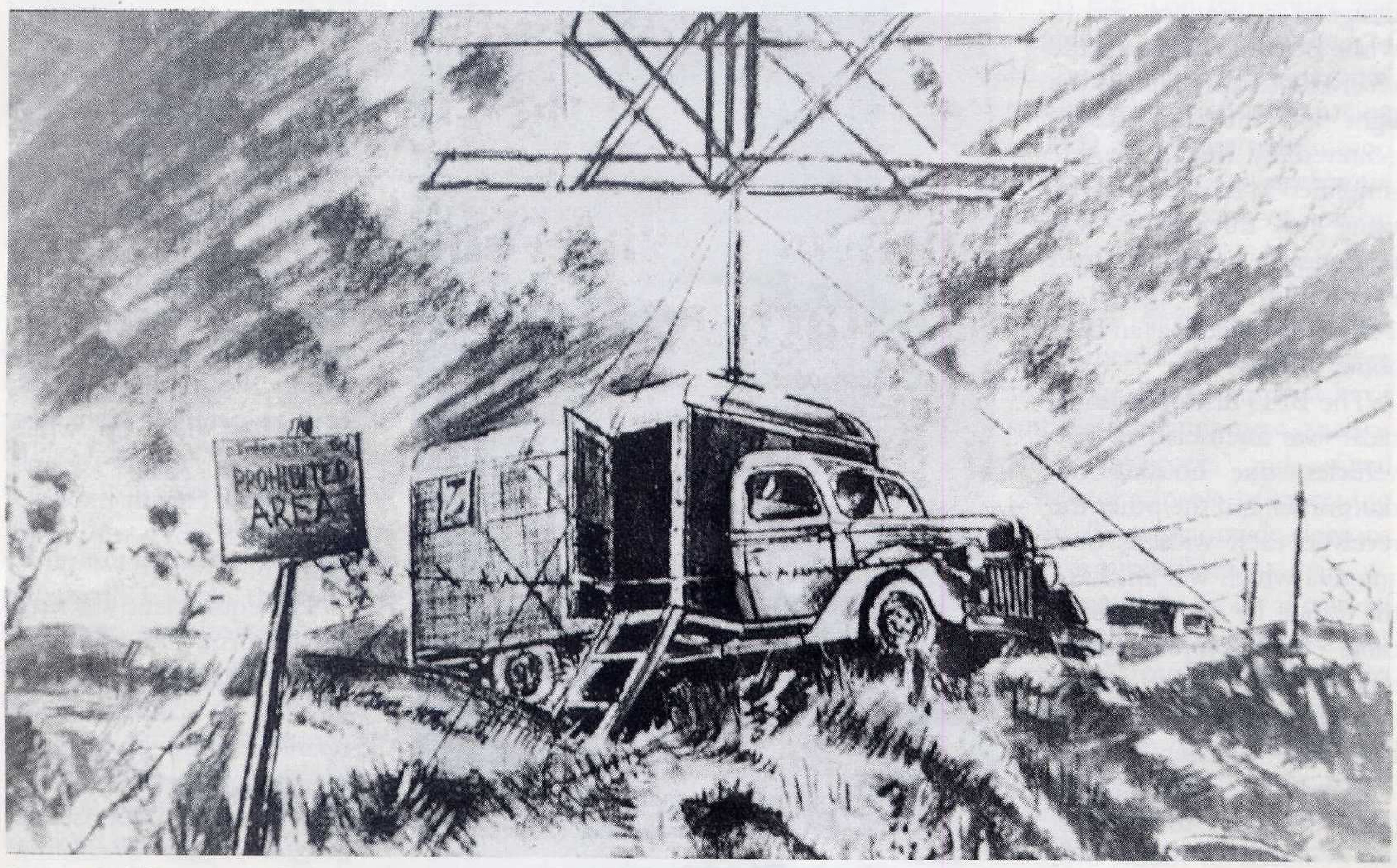


Fig. 7 Mobile JB1 installation from a drawing by the war artist Geoffrey Long

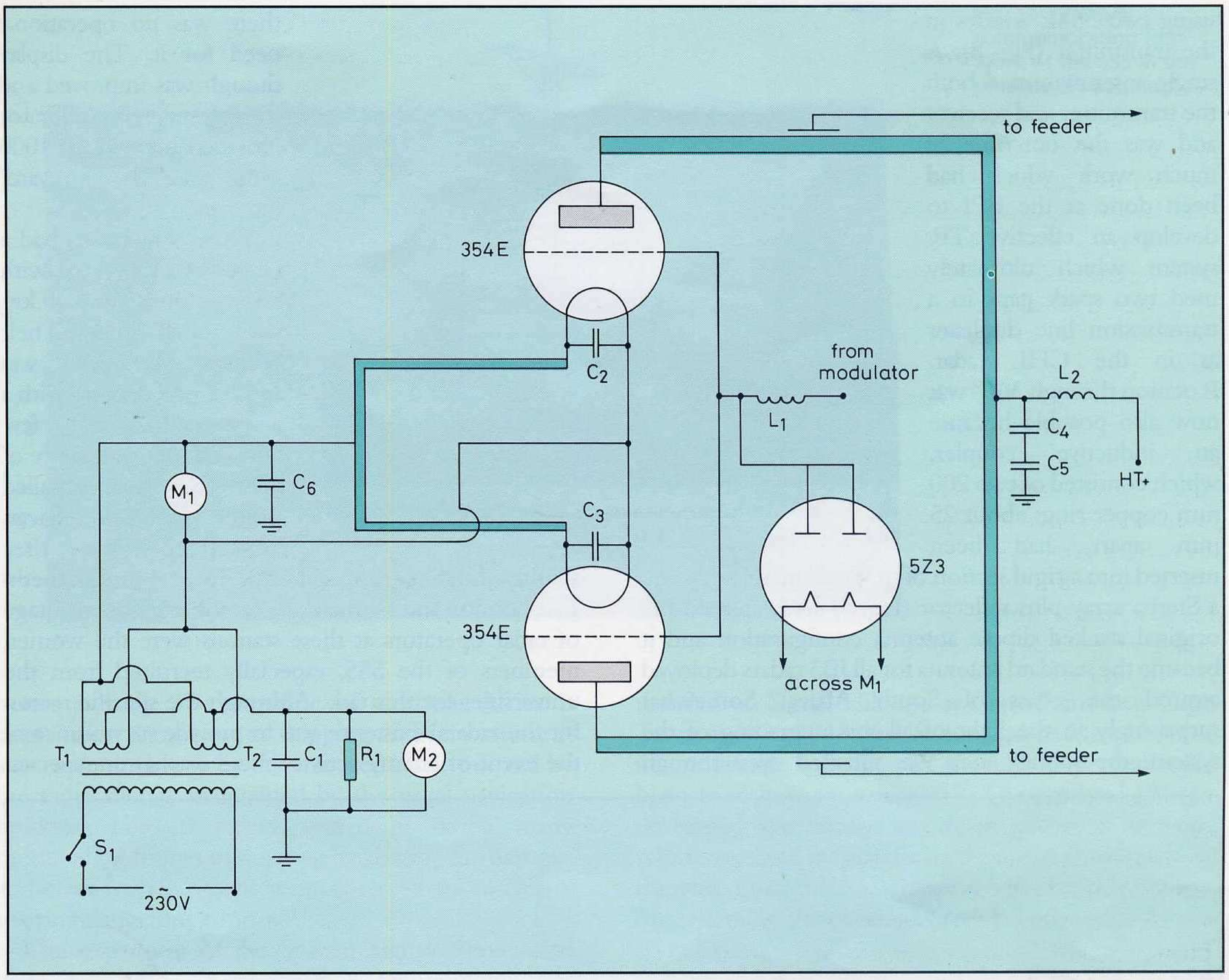


Fig. 8 Circuit diagram of the JB3 transmitter

equipment...in compact units such as might go on the back of a mule[11]'. Captain Gane was ordered to take one of the JB1 radars to Cairo for trials in February 1941 and it was reported that it performed well when used by RAF operators, though quite in what role and with what mode of transport is not clear[4].

The Suez Canal was a prime target for German and Italian air raids and therefore there was a need to set up radar cover along the Sinai coast. The decline in the intensity of the East African campaign meant that Hodges, who had assumed command after Schonland had gone to England in March 1941 to, amongst other things, attempt to improve the supply of British radars and spares to South Africa, was ordered to move the rest of the JB1 radars from East Africa to the Middle East after Hewitt had surveyed suitable sites with the RAF[10]. The JB1s were all in place by 18th June 1941. They were established along the northern Sinai coast at El Arish, Rafah and El Midan and were operational by August in support of the RAF installations in the area[4]. The South African equipment underwent its baptism by fire over the period of the 4th and 5th September 1941 when they were required to provide complete cover for the region for an unbroken 27 hour period while the antenna masts at the RAF radar stations were refurbished. So well did they perform in fact, despite their rather 'home-made' appearance[9], in plotting hostile bombers out to 120 km while under close independent scrutiny that the entire RAF network of MRU (Mobile Radar Unit) 40 MHz radars at El Arish and 60 MHz GL (Gun Laying) sets at El Midan were withdrawn by October 1941[4,8]. The SSS, operating their 'Onions'[6] as they were called, covered that coastline with a small filter room at El Arish until 13th August 1942 when finally all personnel were withdrawn for coastal defence duties back home. Their JB radars were then taken over by the RAF[4].

Coastal defence

The first British radars had in fact arrived in South Africa on 15th May 1940[4]. Some, though, were damaged and there were no spare parts, hence Schonland's visit to England in March 1941 to attempt to speed up the re-supply of both radars and spares. In order, therefore, to provide adequate radar cover against enemy aircraft and ships around South Africa's 3000 km coastline and to provide replacements for the battle-weary JB1s in the Middle East, a further 25 JB sets were ordered from the BPI on 12th June 1941[4]. These new radars were known as the JB3 and operated at the slightly higher frequency of 120 MHz

using two 354E triodes in the transmitter (Fig. 8). A single antenna served both the transmitter and receiver and was the outcome of much work which had been done at the BPI to develop an effective TR system which ultimately used two spark gaps in a transmission line duplexer as in the CHL radar. Rotation through 360° was now also possible because an inductive coupler, which consisted of two 200 mm copper rings about 25 mm apart, had been inserted into a rigid section of the feedline. In addition, a Sterba array plus reflector (Fig. 9) had replaced the original stacked dipole antenna configuration and it became the standard antenna for all JB3 radars deployed around the coast of South Africa. Somewhat surprisingly in the light of all this upgrading of the system, the spongy lock was retained even though

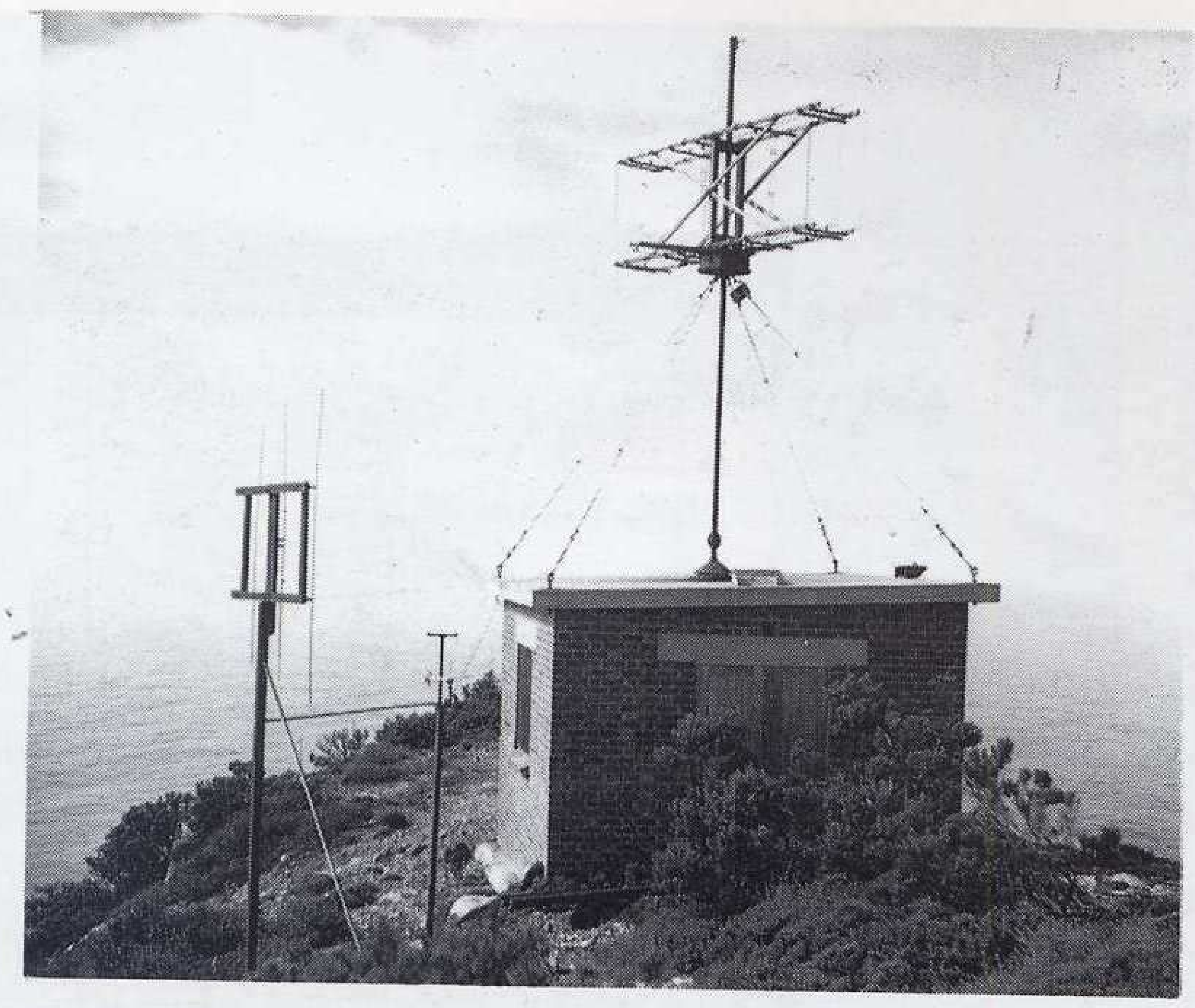


Fig. 9 JB3 Sterba antenna array at the Cape Point coastal site

there was no operational need for it. The display though was improved and the range calibrator provided markers at '1000 yard' and '10 000 yard' intervals.

These new radars had a range of 150 km with bomber aircraft and 30 km with small ships. Their bearing accuracy was about 1 or 2 degrees with a range accuracy of a few hundred metres. Twelve of these JB3s were installed around the South African coast (Fig. 10) and they worked into filter rooms in Cape Town, Port Elizabeth, East London and Durban[4]. By far the largest percentage of radar operators at these stations were the women members of the SSS, especially recruited from the universities for this task. Although the specific reason for the radars' existence was to provide surveillance in the event of enemy activity there was an unexpected

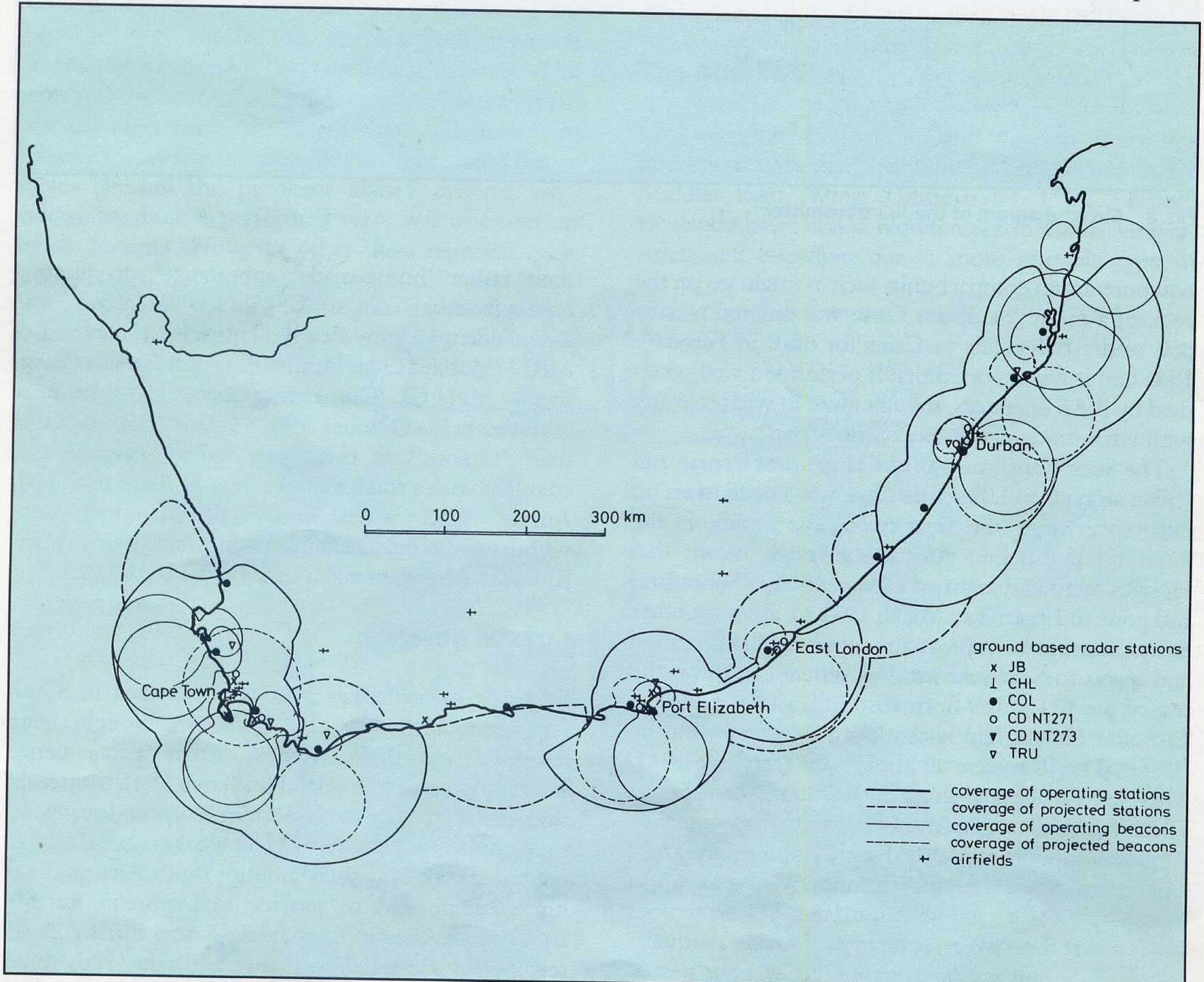


Fig. 10 Wartime map (simplified) produced by Bozzoli and showing the predicted coverage of the various radar systems situated around the South African coastline



Fig. 11 Plaque commemorating the work of the SSS in the present BPI building

bonus as well. The coastline of southern Africa is notoriously dangerous to shipping and in wartime it was made doubly so by the enforced black-out and by the radio silence maintained by the usual navigation beacons. The JB radars assisted in saving many thousands of tonnes of shipping by alerting the harbour authorities when vessels were observed to be clearly steering dangerous courses[4,10].

The expansion of the Special Signals Services to cope with the coastal defence requirements was virtually the first task which faced Lt. Col. Hodges when he returned to South Africa from the Middle East in November 1941 as its new commanding officer, Lt. Col. Schonland having been retained in England for other duties at the request of the Ministry of Supply. From a position in December 1941 of 71 officers and 724 other ranks with no women, the projected numbers, approved by the Adjutant General in November 1942, had risen to 317 officers, of whom 91 were to be women, with 3767 other ranks, 737 being women. In fact these numbers were never actually reached. The peak occurred in December 1944 when 145 officers (28 women) and 1476 other ranks (507 women) were serving in the SSS[4]. The exacting but frequently tedious task of monitoring the screens of the cathode ray tubes was done with great skill by these women and theirs was a key role, made all the more difficult by the absolute secrecy to which they were sworn. They served from late 1942 until the end of hostilities and were under the command of Major Nancy Blue, now commemorated by a special plaque (Fig. 11) in the present BPI building at the University of the Witwatersrand[12].

In April 1942 the promised British (and some American) radar equipment started to arrive in South Africa and finally replaced the JB series which had rendered such outstanding service by the end of 1943. Two Royal Navy type-273 (3 GHz) radars were installed on Signal Hill and at Cape Point near Cape Town early in 1943 after Schonland had used his not inconsiderable influence in the UK to persuade the Navy to make them available[5,10]. These radars had been developed specifically for defence against surfaced submarines and they performed excellently in tracking shipping from their ideal vantage points, thus greatly strengthening the coverage provided previously by the JB radars.

With the invasion of Italy, two SACS Field Radar Sections (FRS) which had been training at No. 3 Signal Depot in Helwan, Egypt, left for Taranto. No. 70 FRS manned the AMES 899 radar station at San Fernando near Naples on 1st August 1944 and was followed on 3rd October 1944 by No. 71 FRS who took over the AMES 8044 station at Ripalto from the RAF[4]. They served throughout the Italian campaign during which they operated the RAF Ground Control Interception (GCI) radars in support of the Allied air forces.

The personalities

Before closing this account of the South African contribution to wartime radar it is worth commenting on the subsequent careers of some of the personalities who played such a major part in it. As mentioned, Schonland went to England in March 1941. There he was soon seconded to the British Army as Superintendent of the Army Operational Research Group within the Air Defence Research and Development Establishment (ADRDE) at Petersham in the rank of colonel. This group was responsible for a significant improvement in the accuracy of the radar-controlled anti-aircraft guns[3,10]. Here, too, he planned the famous Bruneval raid in February 1942 when German radar equipment was captured and yielded a considerable amount of scientific intelligence[9]. In 1944, Schonland, now a brigadier, became Scientific

Adviser to General Montgomery's 21st Army Group. Aftr the war he returned to South Africa and at Smuts's behest established the Council for Scientific and Industrial Research (CSIR) and was its first President from 1945 until 1950. In 1954 he returned to England to become Deputy Director of the Atomic Energy Research Establishment (AERE) in Harwell, and then succeeded Sir John Cockroft as its Director in 1958. He was knighted in 1960 and retired as the Director of the Research Group of the UK Atomic Energy Authority in 1961. In 1962 he received the Faraday medal of the IEE.

Professor Bozzoli became Head of the Department of Electrical Engineering at The University of the Witwatersrand and subsequently Vice-Chancellor of the University in 1969. He also served as President of the South African Institute of Electrical Engineers. Dr. Hewitt established the Telecommunications Research Laboratory (TRL) of the CSIR in South Africa and went on ultimately to become Vice-President of the CSIR. Professor Phillips became Deputy Vice-Chancellor of the University of Natal.

Two members of the SSS whose names have not yet been mentioned are T. L. Wadley and J. A. Fejer. Both played important parts in the SSS during the later stages of the war, particularly when airborne radar was introduced. Like so many other ex-members of this group they joined the TRL after the war and went on to make names for themselves. In 1948, Wadley produced one of the first analytical studies of the feasibility of radio communications underground in mines. Then, in the early fifties, he developed a system of RF signal generation based on the ingenious use of a 1 MHz crystal oscillator, interpolation oscillators and mixers which became known as the Wadley Triple Mix system. This technique was subsequently exploited very successfully by a major British manufacturer of military communications equipment. But probably his most significant contribution was an extremely accurate method of distance measurement using microwaves. The technique is in worldwide use today as the Tellurometer. In December 1957 Jules Fejer published, in *Nature,* the first prediction of the lifetimes of Sputnik 1 and its carrier rocket from the orbital characteristics which had been established within two days of its launch by the former SSS group at the TRL. He emigrated to Canada and soon after to the United States and has since become a world-renowned figure in the field of ionospheric radio physics.

Conclusion

This paper has presented some of the details of a little-known story of great enterprise and initiative in the development and use of radar during World War II. It represents, along with other original work done in Australia, Canada and New Zealand, a small but by no means insignificant Commonwealth contribution to the Allied cause in World War II. The key contributions made by this small group of South African scientists and engineers in designing, constructing and operating their own radar quite independently of the work done elsewhere has been emphasised.

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